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AN EXACT METHOD FOR ANALYSIS OF KINEMATICS FOR MECHANISMS BY USING VECTORS WHICH FORM CLOSED POLYGONS

Assoc.Prof.Dr. Eng. Niculai HAUK
Interdisciplinary Regional Research Centre in Vibro-Acoustic Pollution and Environmental Quality
„Dunarea de Jos" University of Galati

ABSTRACT

Construction machinery equipments are complex, with a high degree of mobility. Their operation is done with groups of hydraulic cylinders equal in number with the mobility. This paper presents an exact calculation, which does not require large computing resources for the kinematics of these mechanisms. Relationships presented can be applied to any mechanism operated by hydraulic cylinders, whatever their mode of installation. Based on these relationships can be developed mathematical models to analyze the dynamics of machines or to make softwares for their control.

KEYWORDS: : hydraulic cylinders, mechanism, hydraulic excavator

1. INTRODUCTION

To simulate the operation of the working equipment of a construction machine must by performed a study for kinematics and dynamics. Knowledge of the response of the equipment is required if is performed the implementation of automatic motion control functions.

Figure 1 shows the case of equipment for the hydraulic excavators whose degree of mobility is 3. Equations closed polygonal contours describe the hydraulic cylinders, with variable length, and the joints of equipment elements. They are of the form [1]

$$\begin{cases} \sum_{1}^{n} d_{1i} \cdot \bar{z}_{1i} = 0 \\ \sum_{1}^{m} d_{2i} \cdot \bar{z}_{2i} = 0 \,. \\ \sum_{1}^{k} d_{3i} \cdot \bar{z}_{3i} = 0 \end{cases} \qquad (1)$$

These are some of the equations necessary to describe the system behavior. The volume of information is large, resulting complex mathematical models. Solving systems of differential equations is done by various methods. Many of them introduce linearization that generate errors difficult to control [2].

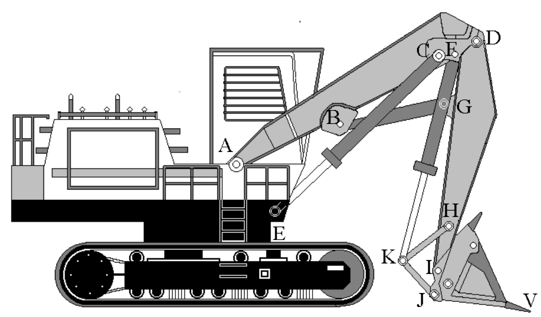

Fig. 1. Hydraulic Excavator with loading equipment

This paper proposes an exact solution of the kinematics of this type of equipment. Are considered adaptations of reference systems introduced, to simplify mathematical modeling.

2. THE ANALYSIS OF REPORTING POSSIBILITIES

Complex mechanisms can be decomposed into subsystems. The subsystems of excavators are:

a) triangles with a variable side (the hydraulic cylinder);

b) quadrilateral with one side possibly variable length.

In this paper will be analyzed the situation from a point.

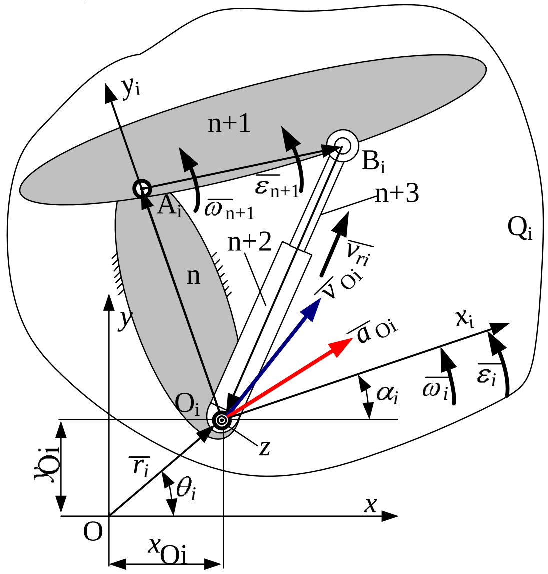

Fig. 2. Due to increased current stroke of hydraulic cylinder, the item "n" rotates counterclockwise.

Reported to the main reference system, the element "n" can rotate counterclockwise ($\overline{\omega}_{n+1}$-Figure 2) or, vice versa (Figure 3). These possibilities depend on the way the hydraulic cylinder is mounted.

To use the same method of calculation are used the next referential systems:

- In figure 2 O *z* axis comes out of plane Q;
- In Figure 3 the same axis enter the plane Q.

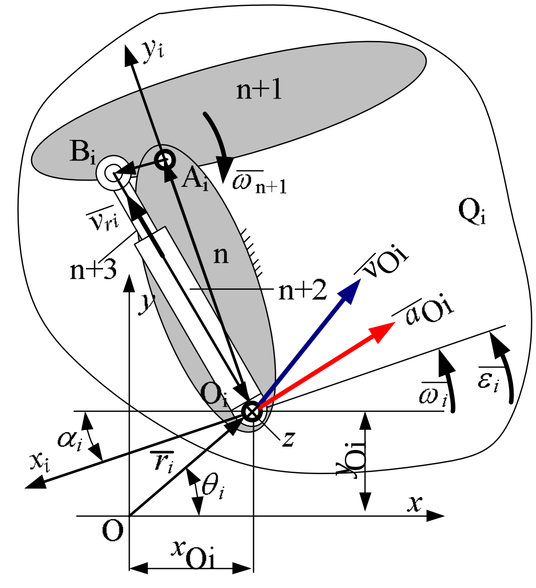

Fig. 3. Due to increased current stroke of the hydraulic cylinder, the item "n" rotates clockwise.

We adopted the following rules for reporting:

-The main reporting system is the axis O-*y*. This is the axis of rotation for the excavator platform or equivalent for other equipment (point O is at ground level);

- The plan *x*-O-*y* is overlaid or parallel to the plane of symmetry of the equipment;

- The plans Q_i, attached to element "n" (Figures 2 and 3), including systems x_i-O_i-y_i, overlaid or parallel to the plane of symmetry of the equipment;

- Axis O_i-y_i has its origin in the joint between the hydraulic cylinder and element "n" and passes through the joint of elements "n" and "n +1".

Reporting parameters calculated to these coordinate axes to main system are differential.

3. CALCULATION OF KINEMATIC PARAMETERS

The Rigid "n +1" is driven by a hydraulic cylinder which is the minimum length L_{mi} and is at the race C_i. In the system of axes x_i-Oi-y_i it is considered the closed polygonal contour consisting of vectors: $\overline{a}_i$, $\overline{b}_i$, $\overline{L_{mi}+C_i}$.

Polygonal contour equation (Figure 4) is

$$\overline{a}_i+\overline{b}_i+\overline{L_{mi}+C_i}=\overline{0} \tag{2}$$

This equation is projected on the coordinate system axis.

$$\begin{cases} a_i\cos\varphi_n+b_i\cos\varphi_{n+1}+\left(L_{mi}+C_i\right)\cos\varphi_{n+2}=0 \\ a_i\sin\varphi_n+b_i\sin\varphi_{n+1}+\left(L_{mi}+C_i\right)\sin\varphi_{n+2}=0 \end{cases} \tag{3}$$

Taking into account the expressions of angles $\varphi_n=\pi/2$ and $\varphi_{n+2}=\pi+\varphi'_{n+2}$ and by making the transformations for the trigonometrical quadrant, resulting

$$\begin{cases} b_i\cos\varphi_{n+1}-\left(L_{mi}+C_i\right)\cos\varphi'_{n+2}=0 \\ a_i+b_i\sin\varphi_{n+1}-\left(L_{mi}+C_i\right)\sin\varphi'_{n+2}=0 \end{cases} \tag{4}$$

from which

$$\sin\varphi_{n+1}=\frac{\left(L_{mi}+C_i\right)^2-b_i^2-a_i^2}{2a_ib_i}$$
$$\sin\varphi'_{n+2}=\frac{a_i^2+\left(L_{mi}+C_i\right)^2-b_i^2}{2a_i\left(L_{mi}+C_i\right)} \tag{5}$$

and

$$\begin{cases} x_{iB_i}=\left(L_{mi}+C_i\right)\cos\varphi'_{n+2} \\ y_{iB_i}=\left(L_{mi}+C_i\right)\sin\varphi'_{n+2} \end{cases} \tag{6}$$

To calculate the angular velocities of

mobile elements, the system (4) it is derived. It takes into account the fact that the functions $\varphi_k = \varphi_k(t)$ describe angles as time dependent.

$$\begin{cases} -b_i \omega_{n+1} \sin\varphi_{n+1} = \\ \dot{C}_i \cos\varphi'_{n+2} - (L_{mi} + C_i)\,\omega_{n+2} \sin\varphi'_{n+2} \\ b_i \omega_{n+1} \cos\varphi_{n+1} = \\ \dot{C}_i \sin\varphi'_{n+2} + (L_{mi} + Ci)\,\omega_{n+2} \cos\varphi'_{n+2} \end{cases} \tag{7}$$

With the substitution $\dot{C}_i = v_{ri}$, we obtain

$$\omega_{n+1} = \frac{\dot{C}_i \sin\varphi'_{n+2} + \omega_n (L_{mi} + C_i)\cos\varphi'_{n+2}}{b_i \cos\varphi_{n+1}}$$

$$\omega_{n+2} = \frac{\dot{C}_i}{(L_{mi} + C_k)\cdot tg\left(\varphi'_{n+2} - \varphi_{n+1}\right)} \tag{8}$$

By the derivation of system (7) and with $\ddot{C}_i = a_{ri} = \dot{v}_{ri}$ angular accelerations can be calculated. The relative velocity parameters , v_{ri} and the relative acceleration a_{ri} are on the hydraulic cylinder axis direction. Their numerical values depend on the operation of the whole system in dynamic mode.

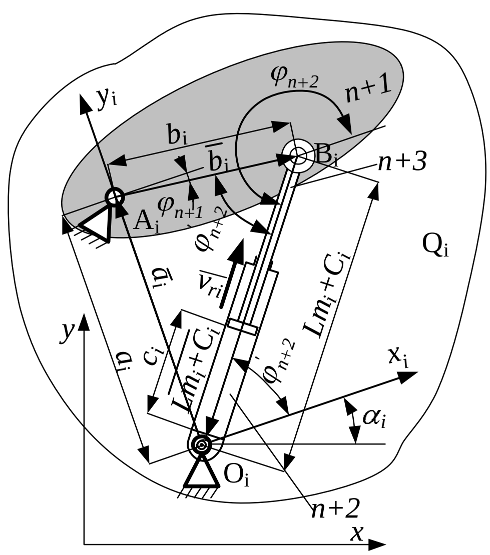

Fig. 4. Scheme with parameters for calculation

By noting

$$t_1 = b_i \omega^2_{n+1} \cos\varphi_{n+1} + \ddot{C}_i \cos\varphi'_{n+2} - 2\dot{C}_i \omega_{n+2} \sin\varphi'_{n+2} - (L_{mi} + C_i)\,\omega^2_{n+2} \cos\varphi'_{n+2} \tag{9}$$

$$t_2 = b_i \omega^2_{n+1} \sin\varphi_{n+1} + \ddot{C}_i \sin\varphi'_{n+2} + 2\dot{C}_i \omega_{n+2} \cos\varphi'_{n+2} - (L_{mi} + C_i)\,\omega^2_{n+2} \sin\varphi'_{n+2}$$

it result the system

$$\begin{cases} -\varepsilon_{n+1} b_i \sin\varphi_{n+1} + \varepsilon_{n+2}(L_{mi} + C_i)\sin\varphi'_{n+2} = t_1 \\ \varepsilon_{n+1} b_i \cos\varphi_{n+1} - \varepsilon_{n+2}(L_{mi} + C_i)\cos\varphi'_{n+2} = t_2 \end{cases} \tag{10}$$

and then

$$\varepsilon_{n+2} = \frac{t_1 + t_2 tg\varphi_{n+1}}{(L_{mi} + C_i)\left(\sin\varphi'_{n+2} - \cos\varphi'_{n+2} tg\varphi_{n+1}\right)}$$

$$\varepsilon_{n+1} = \frac{\varepsilon_{n+2}(L_{mi} + C_i)\cos\varphi'_{n+2} + t_2}{b_i \cos\varphi_{n+1}} \tag{11}$$

4. THE REPORTING OF PARAMETERS CALCULATED TO THE MAIN REFERENCE SYSTEM

Calculation of kinematic parameters towards the reference main system, *x*-O-*y*, with upper index *P*, takes into account the position of *z* axis of the component subsystems.

It is considered the symbol

$$\delta = \begin{cases} +1 & \textbf{-z} \text{ comes out of the plane } x\text{-O-}y \\ -1 & \textbf{- z} \text{ get in the plane } x\text{-O-}y \end{cases} \tag{12}$$

The kinematic parameters have the expressions:

$$\begin{aligned} \varphi^P_n &= \frac{\pi}{2} + \alpha_i \\ \varphi^P_{n+1} &= \varphi_{n+1}\cdot\delta + \alpha_i \\ \varphi^P_{n+2} &= \varphi'_{n+2} + \alpha_i \ \text{ daca } \ \delta = +1 \\ \varphi^P_{n+2} &= \pi - \varphi'_{n+2} \ \text{ daca } \ \delta = -1 \\ \omega^P_{n+1} &= \omega_{n+1}\cdot\delta \\ \omega^P_{n+2} &= \omega_{n+2}\cdot\delta \\ \varepsilon^P_{n+1} &= \varepsilon_{n+1}\cdot\delta \\ \varepsilon^P_{n+2} &= \varepsilon_{n+2}\cdot\delta \\ x^P_{B_i} &= x_{O_i} + x_{iB_i}\cdot\cos\varphi'_{n+2}\cdot\delta \\ y^P_{B_i} &= y_{O_i} + y_{iB_i}\cdot\sin\varphi'_{n+2} \end{aligned} \tag{13}$$

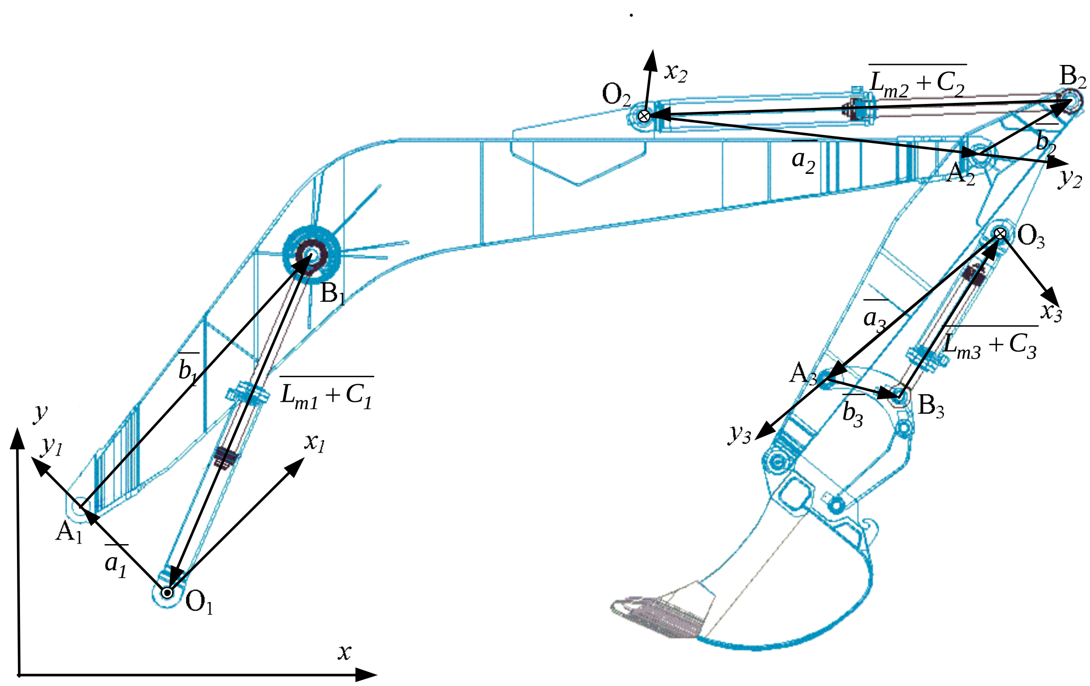

Fig. 5. Reporting systems in case of an excavator with reverse bucket.

With these parameters can be determined, by conventional calculations, all required kinematics parameters. The method has the advantage of allowing simplified calculation schemes.

Only one subprogram that treats polygonal contour is sufficient regardless of the polygonal contour position and direction of rotation of the driven element.

To be used over the entire mechanism, results of subsystems are treated with relations 13.

In Figure 5 is an example of using the method in the case of an excavator with reverse bucket. By acting the arm and bucket mechanisms with hydraulic cylinders, they rotate clockwise. Therefore, axis z of the coordinate systems has the opposite direction. Calculation can be done too if several groups of hydraulic cylinders work simultaneously

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